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Edge Computing for Internet of Things: A Survey

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***Abstract*—The Internet of Things (IoT) is integrating the physical world with the information world. As more and more sensor devices are deployed in the IoT, IoT faces several challenges, such as transmission delay, data storage redundancy, and computing delay. The emergence of edge computing can address these challenges possibly. In this paper, we present an in-depth survey of the integration of edge computing and IoT. First, we briefly introduce the architecture of IoT and discuss a few challenges of IoT. Next, we give an overview of edge computing. We focus on the convergence of edge computing and IoT, and discuss the new architecture and advantages of EIoT. Finally, we summarize the applications of EIoT.**

Keywords—Edge Computing, Internet of Things, Industrial application, IoV

I. Introduction

With the rapid development of information and communication technology, the Internet of things (IoT) technology arises at the historic moment. The emergence and gradual maturity of Artificial Intelligence (AI) technology make the development of IoT technology more rapid and efficient. IoT can be considered as a global network infrastructure composed of numerous connected devices that rely on sensory, communication, networking, and information processing technologies [1]. There is a growing interest in using IoT technologies in various industries [2], but there are some challenges, such as computing delay and so on.

Edge computing (EC) is a new concept in the field of computing. Due to the rapid increase in the number of mobile devices, centralized cloud computing is struggling to satisfy the QoS for many applications. With 5G network technology on the horizon [3-5], the emergence of EC offers the possibility to solve the challenges of IoT. Edge computing is to move computing services and storage resources to the edge of the network which is closer to the end-users, in order to manage resources uniformly, and provide more efficient services for mobile users. The features of edge computing include: dense geographical distribution, mobility support, location awareness, low latency [6].

The convergence of EC and IoT can promote the development of IoT and we name such a combination as EIoT [7]. EIoT can improve the transmission delay, data storage redundancy, and computing delay. In this paper, we present an in-depth survey of the new architecture of EIoT [8].

Based on the previous discussion, our goal is (1) to provide a brief introduction to the IoT and edge computing, (2) to further discuss the potential and role of integrating edge computing and IoT.

To sum up, the main contributions of this paper are: Firstly, the IoT is briefly introduced, including its architecture and main characteristics. Then, the challenges of IoT research are summarized. Secondly, this paper summarizes the hierarchical architecture and characteristics of edge computing. Thirdly, the important insight of this paper is the integration of edge computing and IoT. For this topic, the integration possibility of edge computing and IoT is first discussed. Based on this, the architecture of their integration is further proposed. Finally, the advantages of the EIoT are summarized. Furthermore, the applications of EIoT are summarized.

The content of this paper is organized as follows. Section II introduces the overview of the IoT. Section III introduces edge computing. Section IV discusses the integration of edge computing and IoT. Section V summarizes the applications of EIoT.

II. Internet of Things

In this section, we briefly introduce the Internet of Things (IoT) in Section II-A and summarize the challenges of IoT in Section II-B.

A. *Introduction of Internet of Things*

In the past decade, the IoT has developed rapidly in the field of modern wireless telecommunications. The term IoT was initially proposed to refer to uniquely identifiable interoperable connected objects with radio-frequency identification (RFID) technology. By using RFID readers, people can identify a track and monitor any objects attached with RFID tags automatically [9].

Today, this is a commonly accepted definition for IoT. It is a dynamic global network infrastructure with self configuring capabilities based on standard and interoperable communication protocols. In the IoT, physical and virtual 'Things' have identities, physical attributes, and virtual personalities, using intelligent interfaces seamlessly integrated into the information network [10].

1) *Characteristics*

IoT has three important characteristics: comprehensive perception, reliable transmission, and intelligent processing.

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- **Comprehensive perception**. Perception is the heart of IoT. Comprehensive perception infers to using RFID, smart card, GPS, code, and sensors to obtain the information from objects anytime and anywhere.

- **Reliable transmission**. To transmit information accurately and in real-time, by the integration of various telecommunication networks and the Internet. The stability and reliability of data transmission is the key to ensure the connection between objects [11].

- **Intelligent processing**. Analysis and processing of massive data and information using various intelligent computing technologies, in order to implement intelligent control for objects.

2) *Architecture*

The IoT is an intelligent network system that connects the physical world and the network world. Its typical architecture consists of four levels, as follows:

- **Perceptual recognition layer**. Located at the bottom of the four-tier model of the IoT, the perceptual recognition layer is the foundation of all superstructures. Due to the diversity of information generation modes, the perception layer requires a large number of information generation devices, including RFID, sensors, positioning systems and so on. As more and more devices are equipped with RFID or intelligent sensors, connecting things becomes much easier [12].

- **Communication network layer**. The network is one of the most important infrastructures of the IoT. The communication network layer connects the perception recognition layer and the data processing layer in the four-layer model of the IoT, which plays a powerful role as a link to transmit the data of the upper and lower layers efficiently, stably, timely and securely. These include the Internet, wireless wide area network (4G/5G), wireless (ZigBee/Bluetooth/NFC), wireless local area network (WiFi), wireless metropolitan area network (WiMax) [13].

- **Data processing layer**. How data is stored (databases and mass storage technologies), retrieved (search engines), used (data mining and machine learning), and not abused (data security and privacy protection). This layer also processes all service-oriented issues, including information exchange and storage, data management, search engines, and communication [14-16].

- **Integrated application layer**. The application of the IoT is now in the mature stage of technology, with diversified, large-scale and industrial characteristics, covering intelligent logistics, intelligent transportation, smart power grid, smart home [17], electronic wallet, green building, etc.

The common architecture of the Internet of Things is shown in Figure 1.

B. *Challenges of IoT*

With the rapid development of 5G network and AI technology, the application data will increase significantly, showing the characteristics of diversification, scale, industry and so on, bring some new unknown challenges to the IoT. A more critical situation arises for IoT applications that are time-sensitive, meaning that very short response times are non-negotiable (the smart transportation [18], smart electricity grid [19, 20], smart city [21, 22], etc.) and conventional cloud computing-based service definitively cannot satisfy the demand. We still need to work hard to address these challenges to ensure that IoT devices are well-suited, efficient, and accurate in their applications. Currently, there are some challenges that IoT needs to address:

1) *Transmission delay*

From the perspective of cloud computing, all the data acquired by the perception layer of IoT in the past were transferred to the unified cloud service center for storage and management. For example, the cloud servers can provide massive parallel data processing, big data mining, big data management, machine learning, etc [23]. The centralized service of cloud computing caused some unnecessary data transmission, resulting in slow transmission. Also, more and more objects and devices are connected to the network world, and a larger amount of data is being connected to the network, which will cause more serious delays, conflicts, and communication problems in the future.

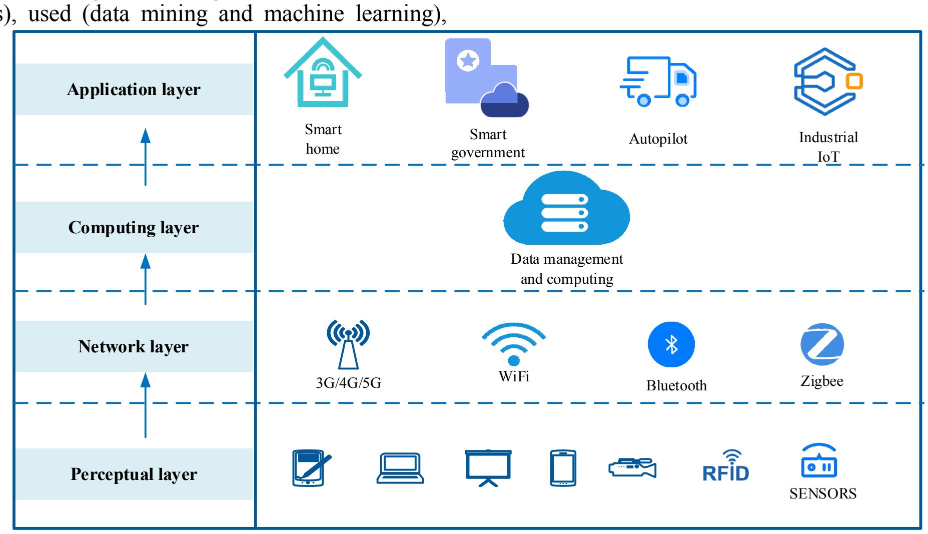

Fig. 1. Architecture of the IoT

2) *Data storage redundancy*

As mentioned above, the cloud computing transfers all data to the central server for storage, resulting in the phenomenon of the server storing a large amount of useless data and repeatedly storing data [24]. The redundancy of data storage not only occupies the storage resources but also bandwidth resources and computing resources. This is also a problem to be solved in the development of the IoT.

3) *Computing delay*

At present, the computing of big data is all carried out in the cloud. Leveraging services of cloud result in high latency and mobility-related issues [25, 26]. With the increasing number of things connected to the Internet, the huge data flow makes the computing slow and inefficient. To mine and analyze the large amount of data generated from IoT requires strong big data analysis and computing skills. The currently developed internet-enabled applications such as surveillance, virtual reality, and real-time traffic monitoring require fast processing and quick response time [27, 28].

Blockchain technology can effectively improve interoperability and system heterogeneity [29]. At the same time, edge computing offers the possibility to solve the challenges of transmission delay, data storage redundancy, and computing delay. We will introduce edge computing in Section III, then discuss the possibilities and opportunities of integrating edge computing with the IoT in Section IV-A.

III. Edge Computing

In this part, we first give an overview of edge computing, then introduce the architecture of edge computing, and introduce key characteristics of edge computing.

A. Overview of Edge Computing

Edge computing is a new computing model. In real life, applications typically run in the following pattern: computing is performed on a cloud server and running on the end user's mobile devices. This method has some defects, such as the accumulation of computing tasks, high delay in information transmission, and poor liquidity.

Based on the above background, academia and the industry have found a new computing model that can solve the above problems, and this computing model is called edge computing. Edge computing infers to data computing and storage that is being performed at the network edge [30-33], that is, computing directly around the end-users. Edge computing can effectively shorten the distance between computing and the users, and reduce the problems of high delay and information transmission.

Edge computing is widely used in many industries. Edge computing enables several new services for enterprises and consumers [34].

B. Architecture of Edge Computing

As shown in fig. 2, the general architecture of edge computing is the joint network architecture of cloud edge collaboration, which is generally divided into a terminal layer, edge computing layer, and cloud computing layer. The three levels are described in detail below [6].

1) *Terminal layer*

The terminal layer is composed of various IoT devices (such as sensors, RFID tags, cameras, smartphones, etc.), which mainly collect and report raw data. The billions of IoT devices in the terminal layer continuously collect all kinds of data, in the form of event sources as the input of application services.

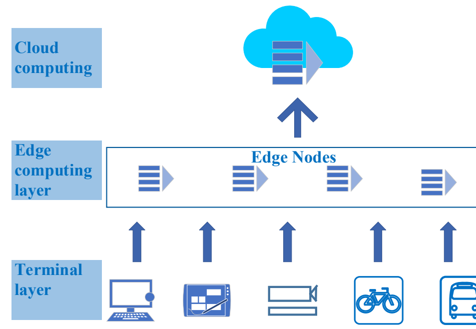

Fig. 2. Architecture of Edge computing

2) *Edge computing layer*

The edge computing layer is composed of edge nodes, which are widely distributed between terminal devices and computing centers. It can be intelligent terminal devices, such as smart bracelets, smart cameras, etc. Or it can be deployed in network connections, such as gateways, routers, etc. Obviously, the computing and storage resources of the edge nodes are quite different, and the resources of the edge nodes change dynamically. Therefore, how to allocate and schedule computing tasks in dynamic network topology is worth studying [35].

3) *Cloud computing layer*

Among the services of cloud + edge computing, cloud computing is still the most powerful data processing center. The reported data of edge computing layer will be stored permanently in the cloud computing center, and the analysis tasks that cannot be handled by edge computing layer and the processing tasks of integrating global information still need to be completed in the cloud computing center [36].

C. Key Characteristics of Edge Computing

Edge computing emerged after the maturity of cloud computing, and its computing model has certain advantages. Among the promising features of EC are included mobility support, location awareness, low latency, and proximity to the user [37]. Edge computing is characterized in terms of high bandwidth, ultra-low latency, and real-time access to the network information that can be used by several applications [38-40]. This section will describe the features of edge computing.

- **Intensive distribution.** Edge computing places computing services around end-users, depending on the architecture of their highly deployed computing platform. Big data analytics can be performed rapidly with better accuracy [41, 42]; the Edge systems enable real-time analytics on a large scale [43].
- **Low latency.** It is also a feature of EC that the end-users compute at the edge of the network close to his or her location, so that the application which is sensitive to time delay can obtain a good computing experience and effectively reduce the time delay of accessing services. Hence, user experience is accounted for high quality with ultra-low latency and high bandwidth [44].

- **High Bandwidth.** The data transmission between MEC servers and smart devices fully exploits the bandwidth [35].
- **Location identification.** Location awareness means that mobile users can effectively perceive and compute when they change their location. Edge-distributed devices utilize low-level signaling for information sharing. MEC receives information from edge devices within the local access network to discover the location of devices [45].
- **User vicinity.** In the edge computing mode, users can have good service experience, because computing resources and services are carried out in the vicinity of users [33].

IV. Convergence of Edge Computing and IoT

In this part, we will introduce three aspects. First, we introduce the opportunity of edge computing and the integration of the IoT, then we introduce the architecture of the integration of the two, and finally, we list the advantages of EIoT.

A. *Opportunities for Integrating Edge Computing with IoT*

The integration of the IoT and edge computing can be developed, which is mainly determined by the current development of the IoT, some characteristics of edge computing, and future development needs.

From the current situation: the development trend of the IoT means that a large number of mobile and wireless devices will be connected [46]. Most of these devices are located at the bottom of the Internet hierarchy structure and may produce a large number of data in various formats at a very high speed. Network bandwidth and computing throughput have become the performance bottleneck of cloud computing.

From the perspective of future development needs, there are the following aspects:

- Firstly, sensors will be ubiquitous in the future, collecting users' privacy data in real-time or at irregular intervals, which puts forward higher requirements for information security.
- Secondly, in the IoT for specific application scenarios, the small data generated by the device needs to be processed locally and in real-time, instead of moving all the data to the cloud for storage and management.
- Finally, future IoT applications need low latency and fast response.

Considering the current development situation of the IoT and its future development, the features of edge computing such as low delay, dense distribution, mobile support, and location awareness can solve these challenges [47].

B. *Architecture of Integrating Edge Computing and IoT*

The new architecture of edge computing and IoT convergence needs to well address some of the IoT challenges we raised in chapter 2, section 2. This system will work across a geo-distributed hierarchy of intelligent edges and large clouds [41, 48]. Next, we introduce how edge computing is integrated into the IoT, and how it to solve transmission delay, data storage redundancy, and computing delay challenges.

Based on the above discussion, the emergence of edge computing can solve some of the challenges of the IoT. As you can see here, we are combining the IoT, edge computing, and the cloud. In this three-tier architecture, all IoT devices are end-users of edge computing. Compared with the previous IoT model that uses cloud computing for data processing, the new three-tier architecture can better deal with the challenges of the IoT.

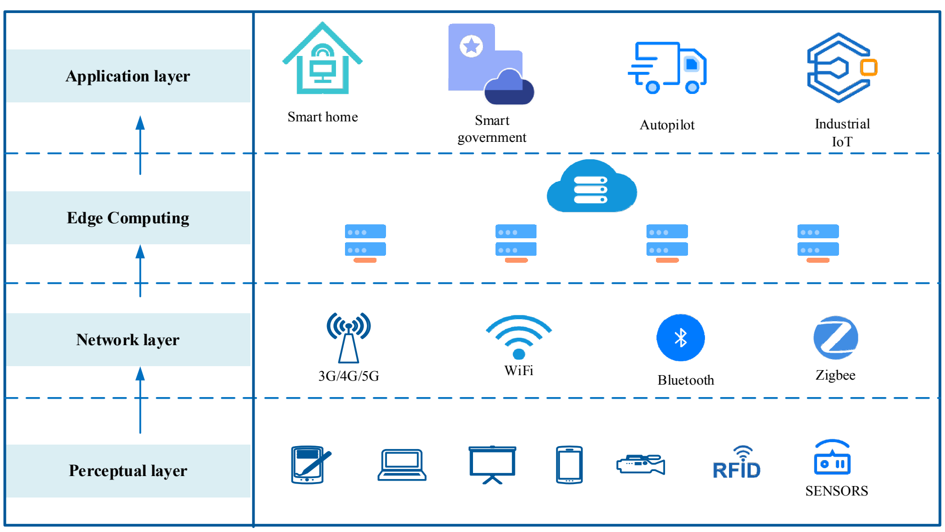

Fig. 3. Architecture of Edge computing with IoT architecture

C. *Advantages of Edge Computing with IoT*

How does EIoT convergence architecture address the challenges of IoT?

- **Transmission delay**. IoT sensors generate a large amount of data, all of which is sent to the cloud, resulting in bandwidth load. The hierarchical architecture of edge computing guarantees a shorter transmission time than any other network [42]. Therefore, the computing process should be as localized as possible to offset the inherent delay in transmitting data over long distances. According to the features of close to the users, context awareness with computing service and use of decision making, to deliver important data to the cloud, real-time analysis data on the edge of the end for processing. This method can reduce the use of the Internet bandwidth, increase the speed of communication and transmission.

- **Data storage redundancy.** Previously, most of the data generated by end-users was sent to cloud servers for processing. With the increasing number of devices connected to the IoT, the data generated by these devices has also increased significantly. If all this data is stored in the cloud server, it will seriously affect the user experience. Therefore, the storage of edge computing can meet this challenge. There are several schemes related to storage balancing in [43, 49, 50]. According to the characteristics of distributed servers in network terminals, edge computing adopts load balancing technology to send different data to edge storage nodes, which reduces the redundancy of data storage.
- **Computing delay.** In the new architecture of EIoT, the computing of data adopts the mode of cloud edge combination. Cloud computing is a centralized computing model based on the central server. Edge computing has many edge servers. The increase in the number of servers improves the speed and efficiency of computing. In general, IoT devices create a voluminous amount of data, continuously, but have only limited computational requests.

In addition to the above, the combination of the two can also guarantee the reliability of the system. Reliability is the cornerstone of IoT service delivery, and a single point of failure is generally unacceptable in many industry scenarios. Therefore, some key operations can't rely on the cloud, and the on-site production system needs to maintain a certain degree of autonomy and autonomy[51].

To sum up, the new architecture of IoT and edge computing fusion can effectively solve some inherent challenges of IoT and perform better in the real world. Next, we will discuss specific application scenarios for the combination of the two.

V. APPLICATIONS OF EIOT

This section describes some application scenarios for edge computing and IoT convergence. It mainly includes the Internet of vehicles (IoV), industrial Internet and time-sensitive applications

(1) IoV applications

With the increasing data transmission volume of the vehicle network, the demand for its delay/delay becomes more and more demanding. Especially in high-speed driving, the communication delay should be within a few ms, and the reliability of the network is very important for safe driving. To achieve safe and effective autonomous driving, a cloud-based vehicle control system is needed because it can collect information from the sensors via a vehicle-to-vehicle network.

(2) Industrial Internet applications

In industrial scenarios, on the one hand, real-time analysis algorithms are directly run through edge computing; on the other hand, the collaboration between edge and cloud is utilized to realize the continuous growth and optimization of models, thus enabling edge analysis technology to enhance the platform's real-time analysis capability. Of course, when the capabilities and connotations of edge cloud collaboration fall into each application scenario, the specific capabilities and concerns will be different, because each edge computing business form has different business requirements for the collaboration with cloud computing[52].

Above, we introduce the new architecture of edge computing and IoT integration and describe its advantages and some application scenarios. However, the fusion of the two is not a common phenomenon at present, and the development of the architecture still faces some challenges.

VI. CONCLUSION

This paper summarizes the architecture, characteristics and challenges of IoT. In order to solve these challenges, this paper proposes a solution for convergence of edge computing and IoT, and introduces edge computing in detail. This paper analyzes the possibility of solving existing problems through the convergence of edge computing and IoT. But the technology is still in its infancy, and needs more research to better promote the convergence of edge computing and IoT.

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